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Dynamic Database

Efficiently convert massive quantities of sensor data into actionable information for tactical commanders

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14. ABSTRACT
As the number of sensors, platforms, exploitation sites, and command and control nodes continues to grow in response to Joint Vision 2010 information dominance requirements, Commanders and analysts will have an ever increasing need to collect and process vast amounts of data over wide areas using a large number of disparate sensors and information gathering sources.

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Motivation

As the number of sensors, platforms, exploitation sites, and command and control nodes continues to grow in response to Joint Vision 2010 information dominance requirements, Commanders and analysts will have an ever increasing need to collect and process vast amounts of data over wide areas using a large number of disparate sensors and information gathering sources.

DARPA's Dynamic Database (DDB) Program is developing technology to efficiently convert large volumes of overhead and airborne multi-sensor data into actionable information for tactical commanders. The DDB challenge is to deal with the problem of ground moving targets in a brigade size area (nominally 30Km. X 30Km.). Typically such an area may contain 1000's of ground moving objects (or targets). The DDB goal is to discover and maintain awareness of the location, kinematics, tracks and identifications of such a large number of objects in such a wide area.

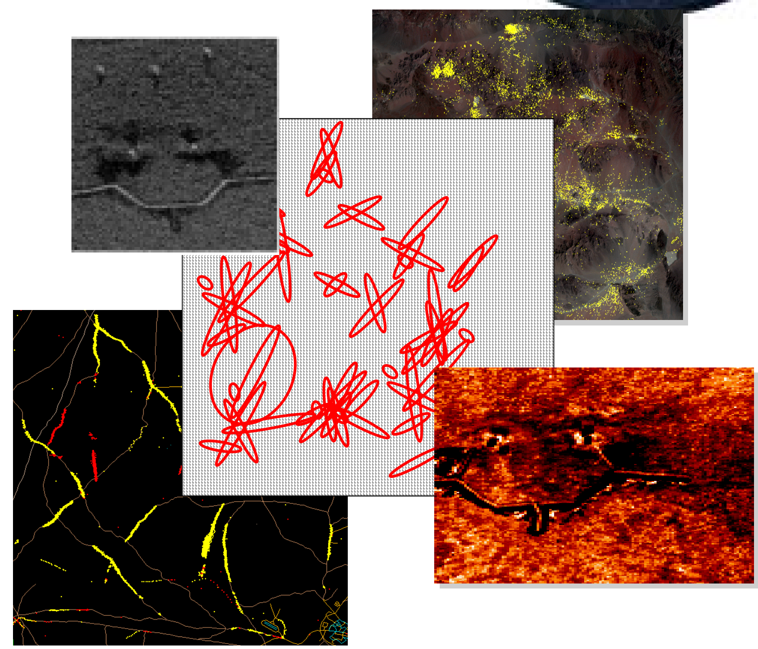
Data relevant to the battlespace are currently collected with a broad variety of remote sensors (SAR, EO, IR, SIGINT, GMTI). These sensors are capable of producing large numbers of reports in a range of different formats. The relevance of these reports and the skills or tools required to interpret them is generally outside the interest of a tactical commander. DDB will provide the automation to to translate relevant data from a sensor perspective to a tactical perspective – that is, a map based view of all objects in the battlespace.

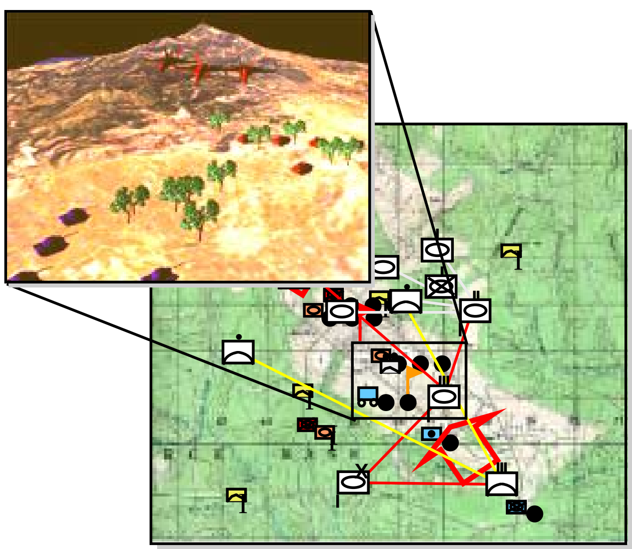
Current processes requires sensor analysts to rapidly sift through large volumes of data pertaining to wide areas to assess friendly status and enemy situations. Today's analysts are uniquely trained with sensor specific skills. This stovepiped process produces reports in differing formats which require further manual analysis and interpretation prior to use by a force commander. The problem is further complicated by the fact that the number of analysts is decreasing and that few are trained to perform multi-sensor analysis.

The manual process is unable to keep pace with the time demands created by the targeting decision cycle required for responding to emerging threats. Hostile ground forces will adopt new tactics that differ from traditional doctrine and which present difficult operating conditions for current assessment systems. Future systems will need to exploit all available sensor data more rapidly and with more diverse cues, in order to develop and maintain a multi-sensor view of the the battlespace, including spatial-temporal history of the battlefield suitable for detecting tactically significant patterns and events. Such a multi-sensor perspective will be required to support decision makers serving intelligence and operational functions at varying echelons of command.

Motivation

- *What the Commanders get ...*
  - Large numbers of partially overlapping sensors
  - 100s of reports; 1000s of images per minute
  - Unregistered, soda straw sensor observations
  - Very high False Alarm Rates
  - Signals - based





- *What the commanders want*
  - Timely Situation Knowledge
  - Comprehensive Coverage ($>$1000 targets over ~1000 Km^2)
  - Accurate target locations with small Circular Error Probabilities
  - Low burden, geo-referenced database

DDB Program

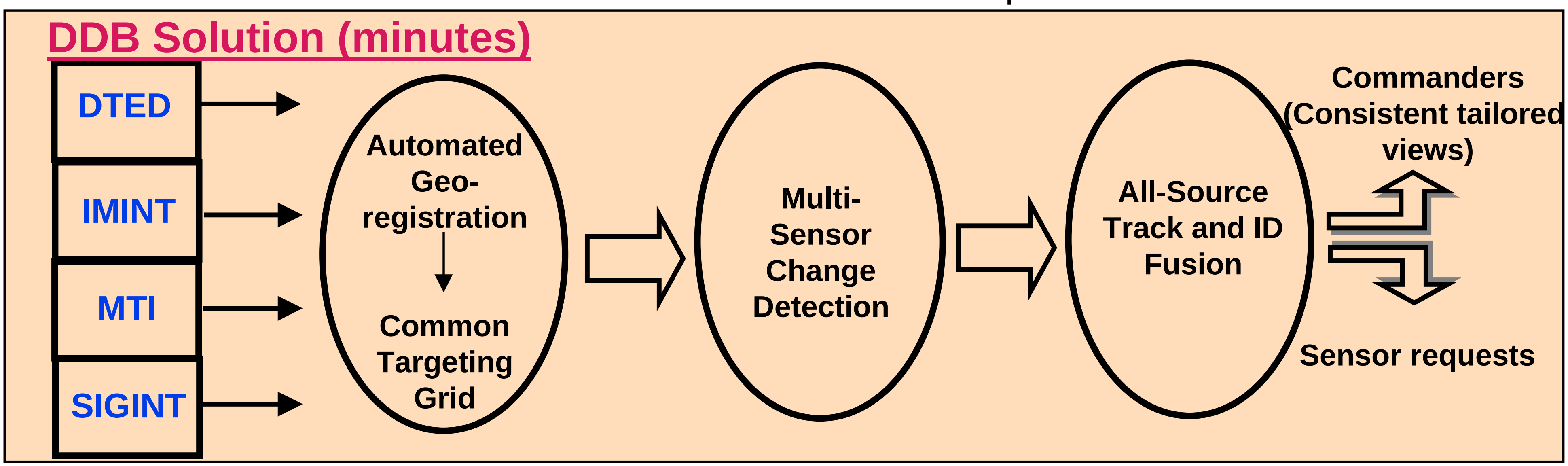
DDB is developing foundational technology to provide commander's with timely, consistent, tailored views of the battlespace. Further, DDB knowledge of objects in the battlespace, and the utility of prior sensor collections, will provide the basis for quantified requests to the collection management process (sensor type, mode, geometry, etc.)

Key technology areas are:

- **Multi-sensor Registration**
  Registration of all sensor data over space and time
  - Automated geo-registration to a common targeting grid
  - DTED / CIB / FFD reference data
  - Object Oriented data structure and services
- **Wide Area Change Detection (WACD)**
  Applied to different sensing domains and leveraging multi-platform, multi-aspect, multi-look potential, with normalcy models, built on-the-fly, to serve as a reference for change recognition.
  - IMINT
    - Multiple parallel & independent (Image & Object Level) change detection paradigms
    - Dynamic adaptation to scene context to manage Pd / Pfa
    - Independent object detection and identification processes
  - MTI
    - Improved positional accuracy
    - Increased track continuity
    - Motion pattern / traffic flow change detection
  - SIGINT
    - Reduced emitter location error
    - New emitter mapping and profiling capability
    - Derivation of tactical communication networks
- **All-source Track and Identification Fusion (ATIF)**
  - Vehicle tracks maintained through *move - stop - move* cycles
  - Aggregates all position, kinematic, identification features for best estimate
  - Recognition of sites, groups, units, and activities

DDB Program

- **Common geo-registered database**
  - Common grid tied to wide area terrain data (DTED, CIB, FFD)
  - Multi-sensor observations (SAR, EO, IR, GMTI and SIGINT)
- **Fusion across sensors**
  - Model based evidence accumulation
- **Track targets and features at object level**
  - Wide area coverage, large numbers of targets
- **Dynamic closed loop tasking overcomes missing/ambiguous data**
  - Self evaluation of database and sensor requests



Dynamic Multi-sensor ISR Database

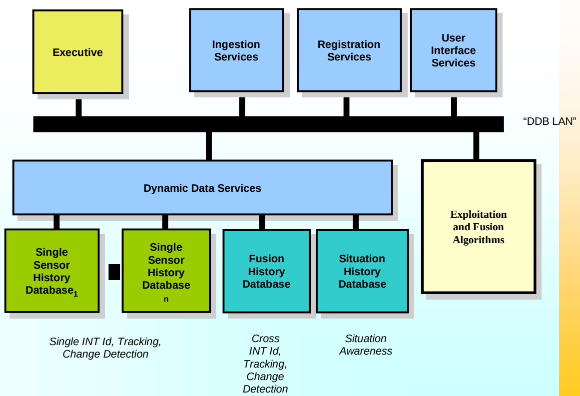
System Design and Technology Integration

- **SDTI Goal:**
  - System Design and Integration – software architecture, hardware architecture and laboratory, and configuration management
  - GUI Design and Development – DARPA INIMEX-based zoomable user interface
  - System / Fusion Gain Modeling
- **Key themes/technologies:**
  - System Design and Technology Integration
    - GUI - DARPA INIMEX-based zoomable user interface to intuitively display sensed and derived fusion data spatially and temporally
    - CESIL - (Component Experimentation and System Integration Laboratory)
      - Co-located Lab - High Performance computers and network co-located at SDTI
      - Virtual Lab - Networked via secure communications to computing resources at co-contractor sites
  - System Modeling
    - Models of sensor and algorithm performance used to analyze and predict performance of a data fusion system
- **Significance:**
  - System Design and Technology Integration
    - Provides a distributed integration network at multiple security levels for software development and information exchange
    - Provides platforms and environment to transition components of DDB to demonstration
  - System Modeling
    - Predict impact of different sensors
    - Describe trade between better sensors and more sensing *(Quality, quantity, revisit rate, etc.)*
    - Evaluate sensor mix issues
    - Develop fusion algorithm control methods
    - Predict system performance

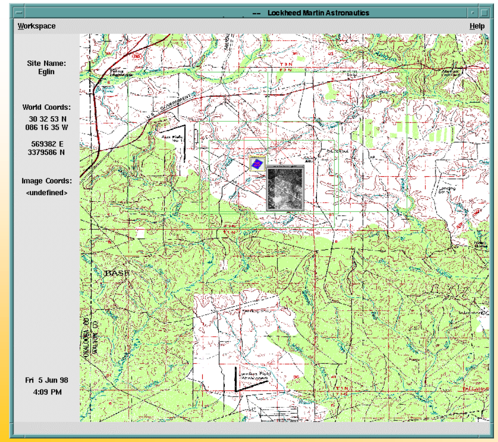
System Integration and Modeling

System Architecture

- Component Algorithms
- High Performance Data Services
- Executive and Control



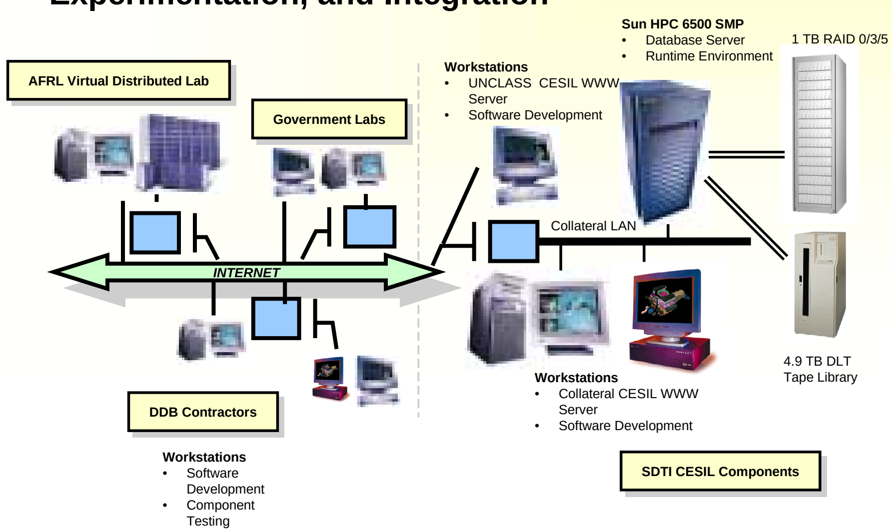
Graphical User Interface



- Utilizes the DARPA INIMEX zoomable interface concept
  - Provides intuitive display of temporal and spatial aspects of the data
- Integrates external sensed data and internal fusion products on data layers

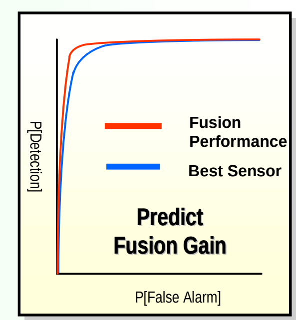
(CESIL - Component Experimentation and System Integration Laboratory)

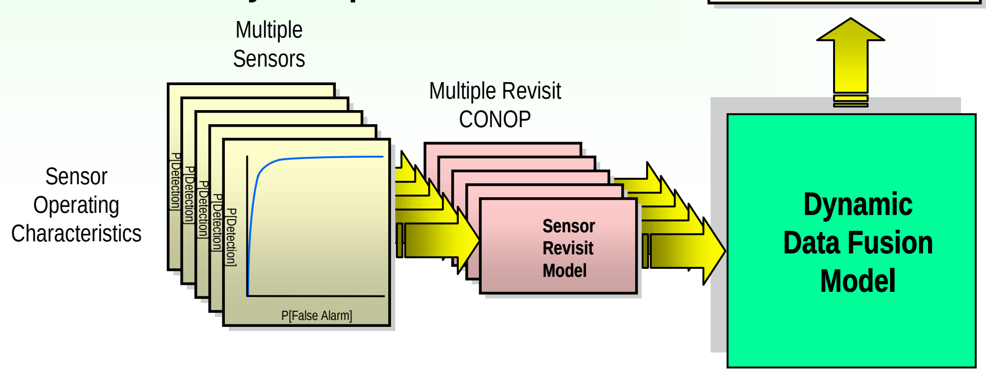
- Computing Assets for Distributed Development, Experimentation, and Integration



Fusion Performance Modeling

- Define sensor combinations that result in best system performance
- Develop fusion algorithm control methods
- Predict system performance





DDB Architecture

The High Performance Data Store (HPDS) provides the dynamic database environment to rapidly store, index, retrieve, and share massive quantities of data among DDB components. This data includes not only sensor and foundation data, but also results of the detection, fusion, and reasoning algorithms. Therefore, a critical part of the DDB system is a rich common object-oriented schema that includes the raw sensor data, registration data, features, associations such as tracks, and models of real world entities and their environment.

Typical commercial DBMSs, used as-is, cannot meet DDB's requirements to keep up with the constant stream of incoming sensor data and be able to index it so that spatially and temporally coincident data can be efficiently retrieved. The HPDS is built using an object database extended with hierarchical spatial and temporal indexes for this purpose. To make room for new data, obsolete data will be efficiently purged as necessary without significantly impacting performance.

Sensor errors, registration errors, association errors, and possible errors in identification all contribute to uncertainty in DDB results. We are currently adding a rigorous representation of uncertainty to the schema, and eventually in the database query engine itself, that will allow algorithms to correctly reason on and combine uncertain information.

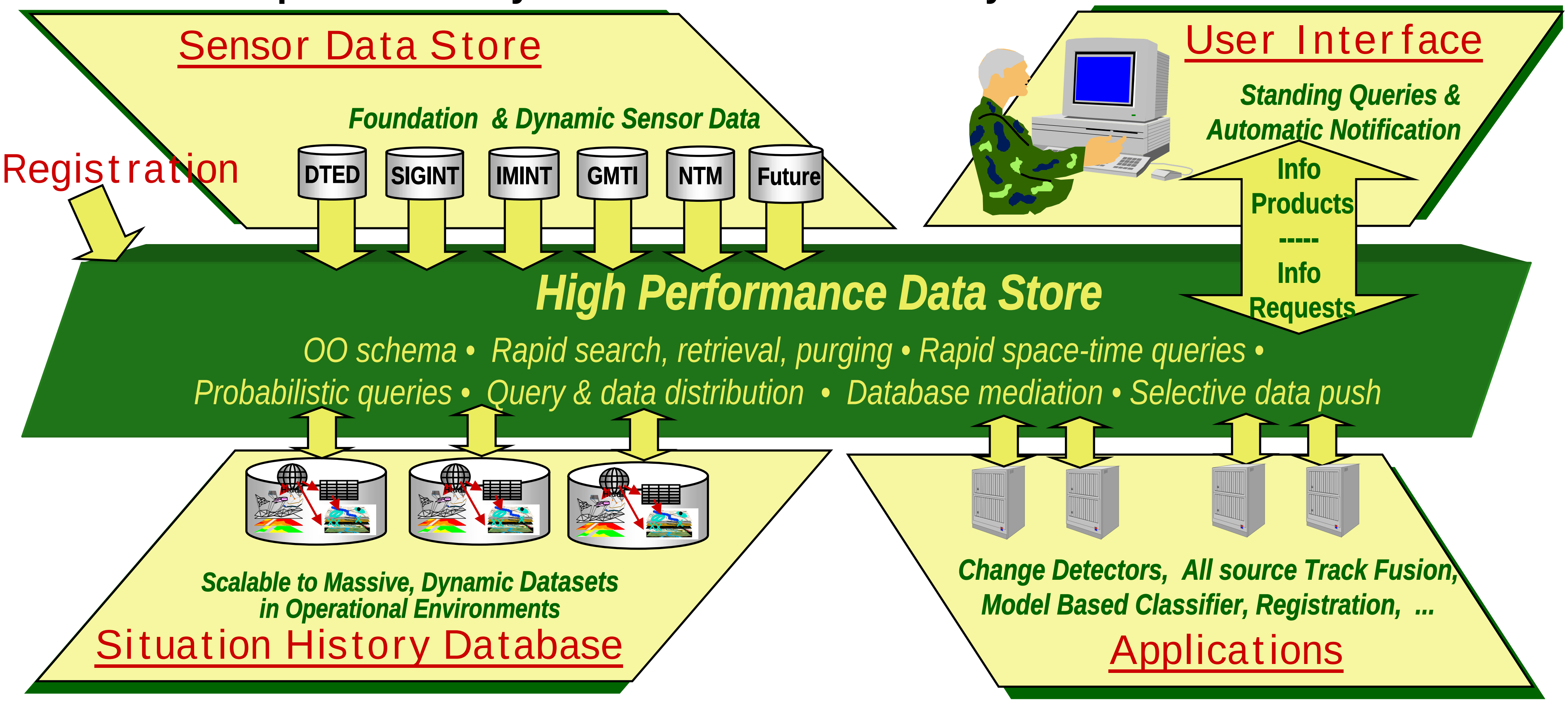
In addition, HPDS provides active database mechanisms that can trigger an algorithm to run on new data, notify a user of a significant event, or determine what computations must be run to answer a user's ad hoc query. The system can be “loosely” distributed across multiple locations, with data and queries selectively replicated to support an operational environment with possibly unreliable communications networks.

DDB Architecture

Enables Sensor Data Access and Technology Growth

- **Scalable Database architecture overcomes limitations of data ownership; Enhances:**
  - **Data sharing, Interoperability**
  - **Technological growth - applications and visualization**

  Leverages COTS thrusts in ‘open systems’ & ‘object-oriented databases’
  - **Explores military needs which exceed likely commercial interests**



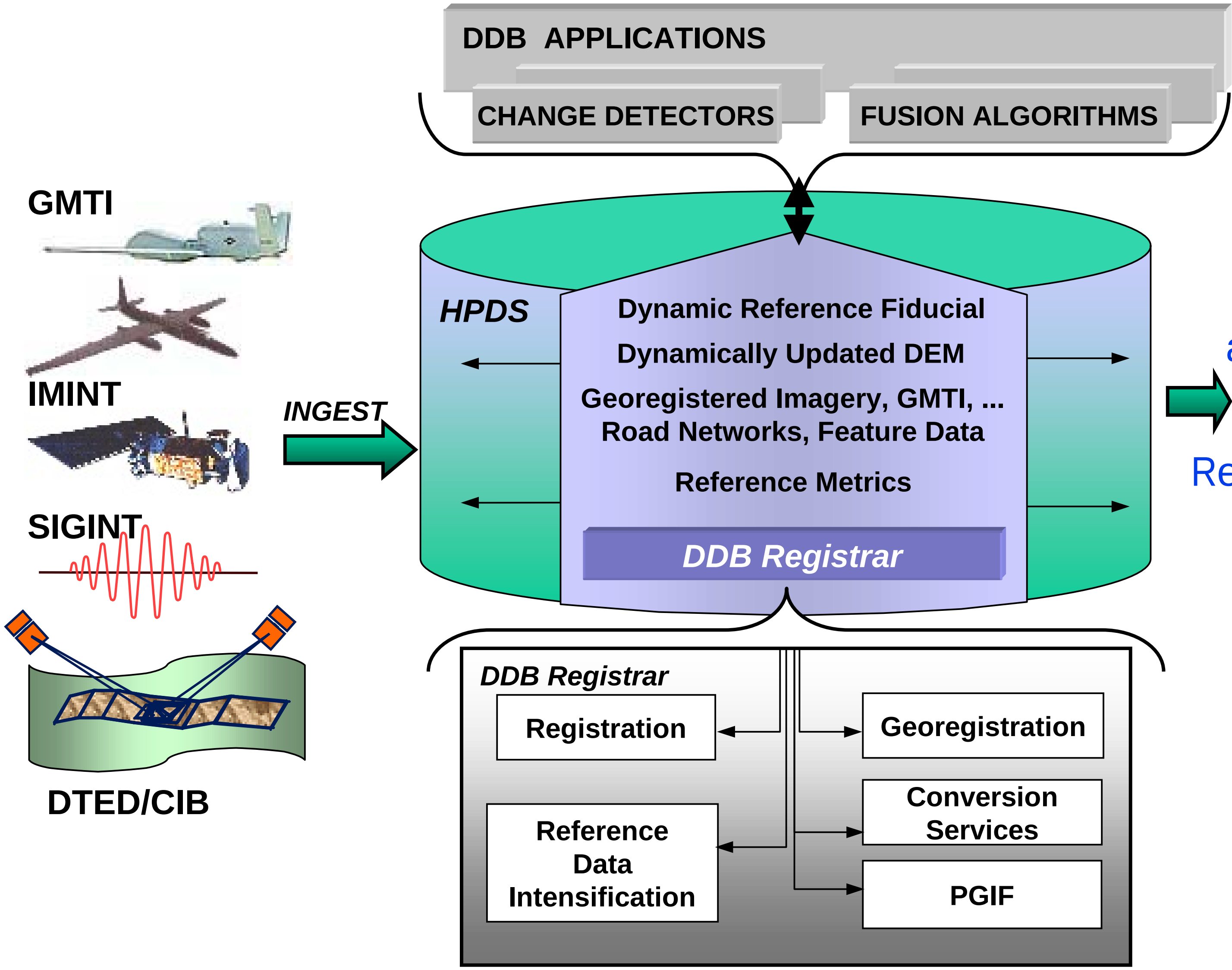
Registration

- **Registration Goal:**
  The DDB Registration process of geospatial normalization supports accurate and efficient change detection and fusion processes. Multi-INT (GMTI, SIGINT, IMINT) data is reoriented to a common targeting grid during ingest
  - Globally-consistent multi-temporal observations share common map coordinates
  - position accuracy increases over time through complementary sensor observations

- **Key themes / technologies:**
  - all DDB objects geolocated in 3-D (latitude, longitude, elevation)
  - Cross platform systematic errors are autonomously removed or reduced during “background” processing
  - Registration metrics provide operator insight into DDB registration accuracy
    - Registration success metric
    - CE90/LE90 error statistics
  - Position knowledge of DDB objects and reference data continuously refined and improved over time
    - Cross-INT salient features automatically defined and refined as Precision Georegistered Invariant Features (PGIF)
    - PGIFs are features that occur across Multi-INT data (i.e. road intersections, stationary rotators,…)
    - PGIFs are used to make associations in Multi-INT data for error propagation and correction

- **Significance:**
  Geospatial Normalization Enables Change Detection and Fusion
  - Performance of OLCD is significantly improved (higher detection rate, lower false alarm rate)
  - Performance of GMTI tracking algorithms is improved (fewer track losses, higher fidelity tracks)
  - Ability to support multi-INT wide area change detection
  - Ability to reduce false detections and false associations

Registration of all sensors to a Common Targeting Grid



Absolute Geospatial accuracy for targeting (~10 m.)

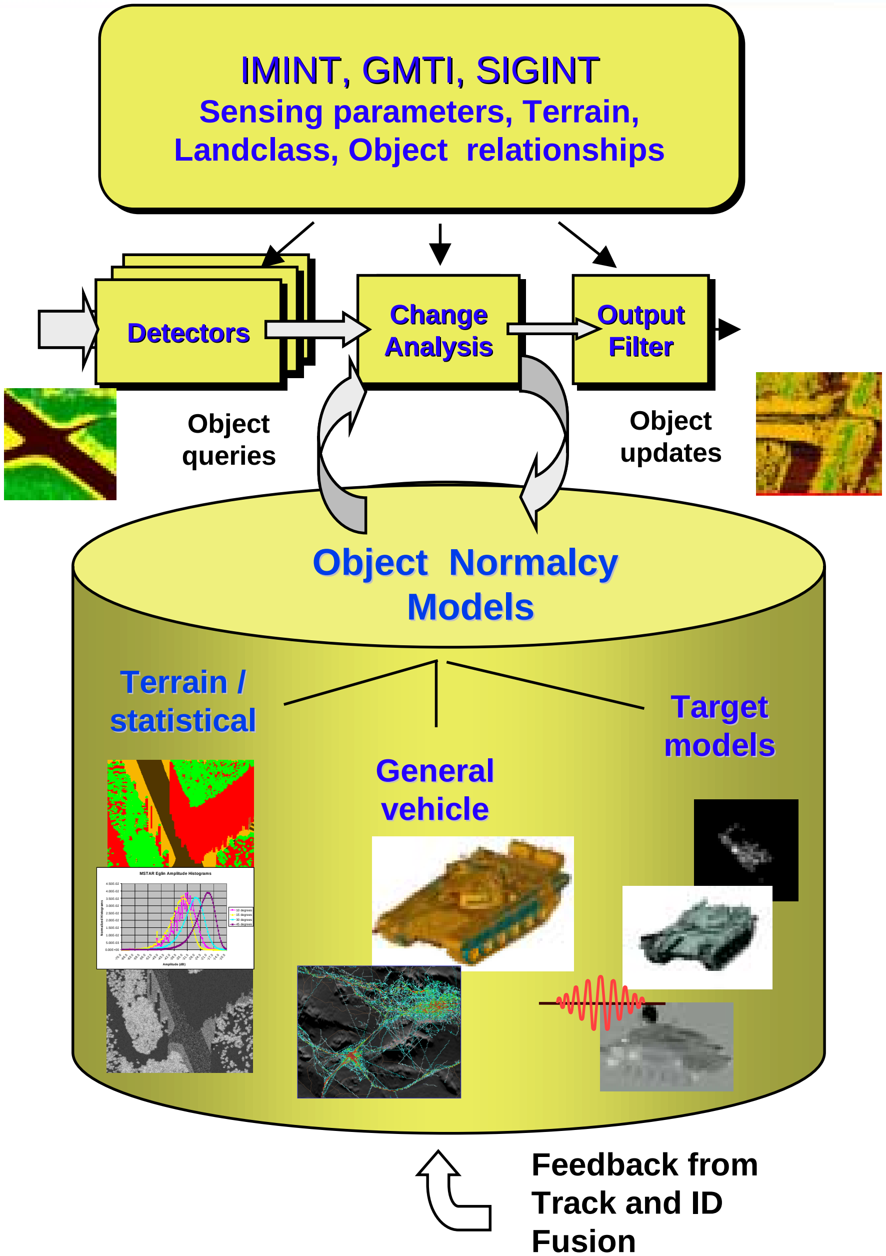
Relative Georegistration for change detection (<1m.)

Dynamic update of reference data

Normalcy Models

- **Nomalcy Modeling Goal:**
  - Normalcy Modeling for Change Detection
    - Multispectral Image Intelligence (IMINT) for Targets and Scenes
    - Emissions Patterns (SIGINT)
    - Traffic Patterns (GMTI)
- **Key themes / technologies :**
  - High-Fidelity Off-line Modeling
  - Rapid On-line Target and Scene Modeling for On-line Reasoning
    - Target Configurations, Articulations, and Extended Operating Conditions
    - Scene Geospatial and Statisitical Clutter Variations
  - Sensor Acquisition Geometry Modeled On-line
  - Multispectral Segmentation of IMINT Data to Improve Context
  - Multispectral Validation of Technology Against Multiple Sensors
  - On-line Geospatial and Temporal Learning to Update Normalcy Models and 3-D Site/Region Context
- **Significance:**
  - Integrated Multispectral Context Based Change Detection
    - Scene Context from IMINT
    - Behavioral Context from GMTI and SIGINT
  - Ability to Separate Significant Changes from Normal Variance Using Multispectral Sensors
  - Exploit Strengths of Each Sensor through Data Fusion at Reasoning Levels
  - Rapid 3-D Context Generation and Updates for Sites and Regions of Interest
  - Multispectral High-Fidelity On-line Target Signature Generation for Target Reasoning

Normalcy Models enable Wide Area Change Detection



Normalcy models provide context for detection thresholds

- Is this a region of high clutter?
- Was it there on the last sensing pass?
- Has it changed state or shape?
- Is it emitting as expected?
- Is it moving in a new way, place, or time?

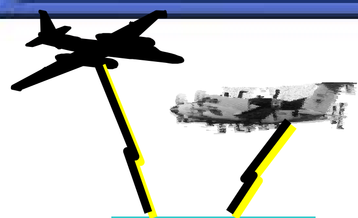
Combined multi-sensor data is required to derive normalcy

- Spatial, Temporal, Feature based representation of scene content, background, and behavior.

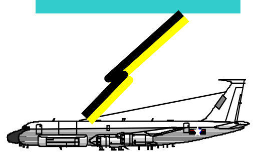
SIGINT Change Detection Approach

- **SIGINT Change Detection Goal**
  - Using data from multiple platforms provide a significant increase in COMINT emitter geolocation accuracy and a significant increase in tracking performance.
  - Develop alternate methods of automated evaluation of SIGINT data that can be used to find tactically significant events.
- **Key themes / technologies**
  - Multi-Platform Track and ID:
    - Data on each emitter from multiple sources fused into single report
    - Platform type recognition
    - Tactical alerts
  - Emission Density: Determine distribution of significant RF activity across the battle field
  - Emission Profile: Derive modes of activity based on temporal communication patterns and determine normal and abnormal activity.
  - Communication Networks: Find and identify the nodes and links of operational communication networks
- **Significance**
  - Multi-Platform Track and ID:
    - Improved geolocational accuracy
    - Greatly improved ID and vehicle recognition
    - Ability to extract intent and alerts
  - Emission Density: Aids in the location and ID of militarily significant sites and trends
  - Emission Profile: ID of tactically significant events and activities.
  - Communication Networks: Identifies command centers and command networks

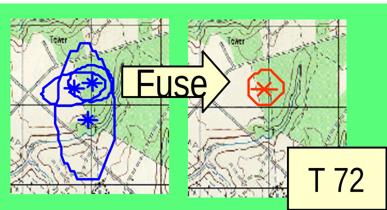
SIGINT Change Detection Approach



SIGINT INGEST

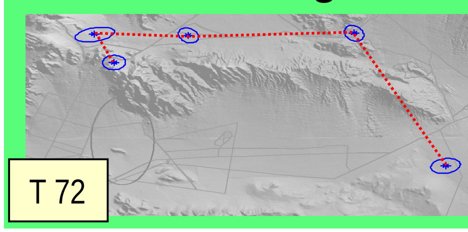


Automated ID



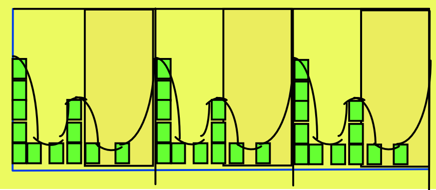
Multi-Platform Emitter Correlation

Multi-Platform Emitter Tracking



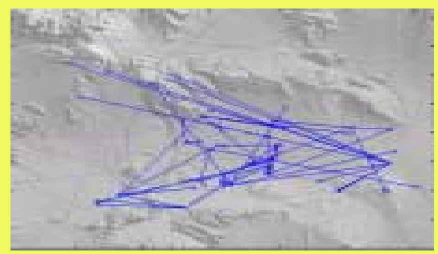
Multi-Platform Correlation/Fusion

Emission Profile

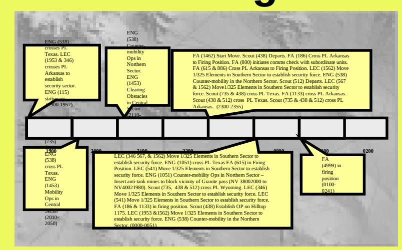


Emission Density

Comm Networks



Change Detection/ Event Recognition



Coarse Reasoning

- **SIGINT Ingest:**
  - **Ingest data from multiple systems into the HPDS**
- **Automated ID:**
  - **Use results from AFRL (Rome) work to supply Speaker ID, Vehicle ID and Internal ID**

- **Geolocation Correlation and ID**
  - **Multi-Platform Emitter Correlation** - correlates reports based on geolocation and ID.
  - **Multi-Platform Emitter Tracking** - correlates emissions over time based on ID parameters

- **Analysis of spatio-temporal structure of RF activity:**
  - **Emission Density** - exploits spatial features of the battlefield
  - **Emission Profile** - exploits periodic activity of the battle space
  - **Communication Network** - maps lines of communication between entities and echelon levels.

GMTI Change Detection Approach

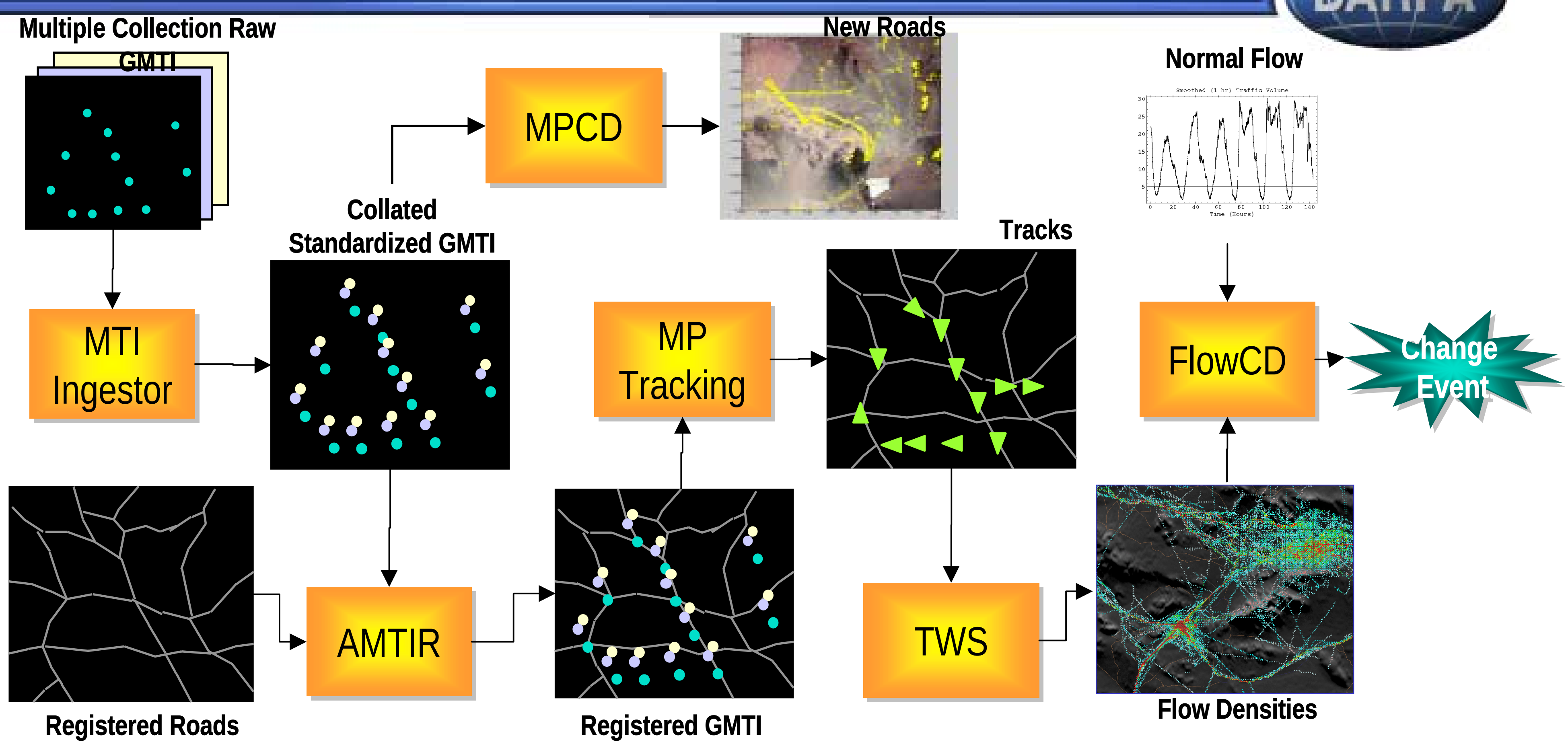
- **GMTI Change Detection Goal:**

  GMTI change detection will improve the ability to detect and track dynamic ground forces. GMTI Sensor History Database takes advantages of single and multiple GMTI platforms (different viewing angles) to increase track continuity of high value targets, and provide early indications of significant movement change.

- **Key themes / technologies:**
  - MTI Ingestor - Ingests GMTI from multiple sources: Joint STARS MC44, AFRL Normalized MTI Format (NMTI), etc. to construct persistent common GMTI database objects representing the measurements and sensor collection metadata
  - Absolute MTI Registrar (AMTIR) - GMTI sensor independent debiasing of GMTI measurements. Registration relative to (registered) road network
  - Multiple Platform GMTI Tracking - Fusion o f GMTI from multiple sensors. Uses terrain context: roads, terrain mobility constraints
  - Trip Wire Sentry (TWS) and Flow Change Detection - Measures movement of traffic flow. Statistical Modeling of normal flow and detection of significant change in flow
  - MTI Pattern Change Detection - Detect new active Lines of Communications, active sites and spatial-temporal features of GMTI linear and isolated clusters

- **Significance**
  - Provides rapid retrieval of common representation of GMTI using spatial-temporal collections
  - Improves multi-source fusion via improved position accuracy
  - Improves track continuity, purity, position and velocity accuracy
  - Provides indications and warning of significant movement
  - Detect active sites, potential Lines of Communications, barracks, motor pools, construction

GMTI Change Detection Approach



Ingest

- Common representation
- Sensor History Database
- Spatial-temporal indexing

Register

- Improved position accuracy
- Improves multi-source fusion

Multi-Platform Tracking

- Improved track continuity, purity, position and velocity accuracy

Traffic Flow

- Wide area movement estimates
- Indications and warnings of significant movements

AMTIR - Absolute MTI Registrar	MP - Multiple Platform	MPCD - MTI Pattern Change Det.	TWS - Trip Wire Sentry	FlowCD - Flow Change Det.

IMINT Change Detection Approach

- **IMINT Change Detection Goals:**
  The DDB IMINT Change Detection Approach exploits multi-sensor, multi-look, and multi-temporal imagery using a unique combination of image-level and object-level change detection algorithms to provide real-time recognition of object presence and extraction of ID features.

  These complimentary algorithmic approaches tend to be orthogonal enabling decorrelation of false alarms. This enables the IMINT Change Detection algorithms to run at higher sensitivity levels with greatly reduced false alarms. This innovative approach to change detection produces a semantically richer set of features that are used for high confidence discovery of militarily significant object changes for simultaneous tracking and target identification.

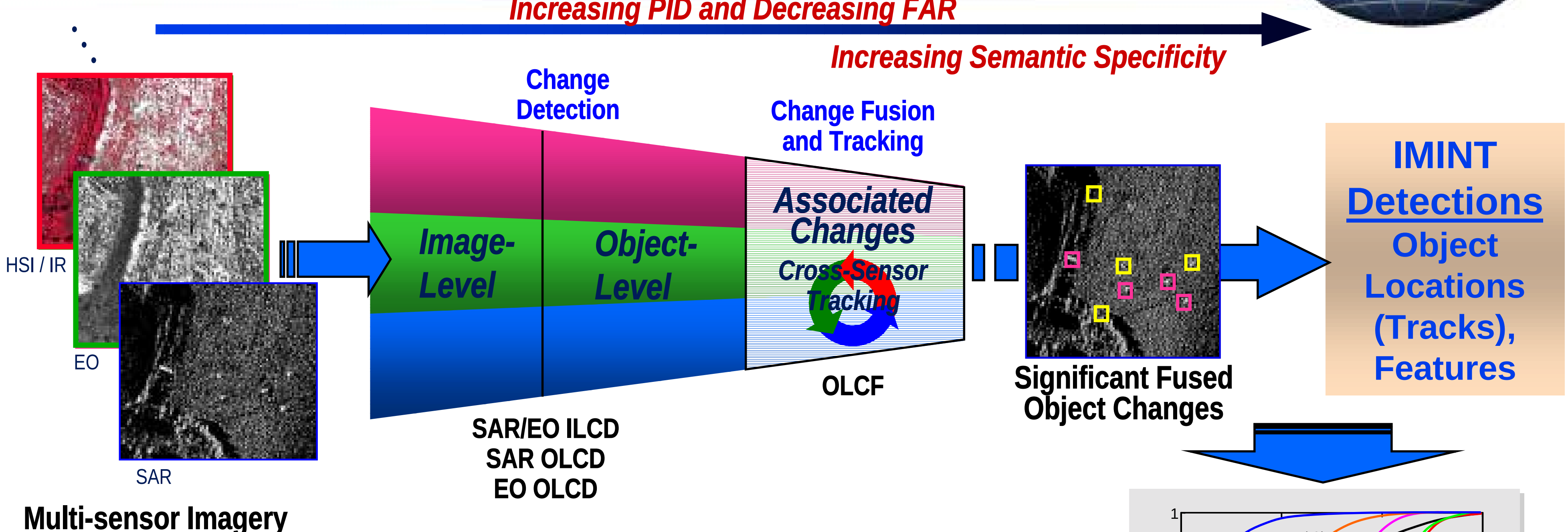
  This approach overcomes current state-of-the-art change detection approaches which do not perform robustly under extended operating conditions (e.g., scene diversity, target adjacency, and partial obscuration), and which do not manage false alarms well when operating at high sensitivity levels (I.e., high Pd) or when subject to nuisance parameters like aspect diversity and cardinal angle flash.

- **Key themes / technologies:**
  - SAR Object-Level Change Detection (SAR OLCD)
  - EO Object-Level Change Detection (EO OLCD)
  - SAR/EO Image-Level Change Detection (SAR/EO ILCD)
  - Object-Level Change Fusion (OLCF)

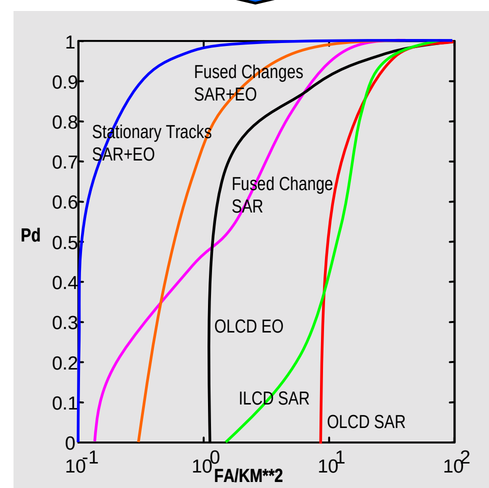
  ILCD performs temporal segmentation followed by spatial anomaly detection which compliments OLCDs spatial segmentation followed by temporal anomaly detection. The use of normalcy models as well as context to increase Pd/Pfa is used by all three change detection approaches.

- **Significance:**
  - Effective image screening and cueing -- vast data reduction of multi-sensor imagery to ID of militarily significant entities
  - Fusion gain cross-sensor, cross-algorithm, across extended operating conditions
  - Maximum use of all available multi-sensor imagery:
    - Maintain performance over wide areas using low quality data (e.g. Stripmap, search mode)
    - Extend performance over focused areas through use of limited high quality data (e.g. Spotlight)
  - Dynamic adaptation to scene context through use of “Normalcy” models
    - Background adaptation
    - Change detection
    - Target identification and state

IMINT Change Detection Approach



- Sensor history drives "Normalcy" modeling which enables image response prediction under various conditions
  - Image-level
  - Object-level
- Object Level Change Fusion exploits image- and object-level false alarm decorrelation
  - Higher Pd
  - Lower Fa
- Locally adaptive algorithms responsive to extended operating conditions for higher confidence discovery



Multi-look -- Multi-temporal -- Multi-sensor -- Multi-algorithm Fusion

All-Source Track & ID Fusion Approach

- **All Source Track and Identity Fusion (ATIF) Goals:**

  The All Source Track and Identity Fusion (ATIF) component takes as input MTI, IMINT, and SIGINT tracks. It produces as output all source tracks by associating the input tracks, and fusing the corresponding kinematic and attribute state information. ATIF is currently being tested on simulated input tracks, as well as tracks derived from JSTARS MTI and several sources of SAR and EO IMINT data.

  From a tracking perspective, ATIF has two primary benefits. The first is that it improves track continuity -- it enables the warfighter to maintain target track longer because ATIF can track through move-stop-move cycles by associating MTI and IMINT hits. Maintaining target track longer simplifies situation estimation because analysts have fewer track fragments to interpret. Current testing indicates that track continuity can be extended by approximately a factor of 3-4.

  The second primary benefit of ATIF is that it improves state estimates. Target classifications are improved via fusion of classification information across INTs and over time -- the greatest impact of this is on MTI-based mover tracks which can be provided with target classification information via association to SIGINT or IMINT tracks that are far easier to classify. Kinematic state estimates are also improved via fusion of kinematic information across INTs and over time -- the greatest impact of this is on tracks derived from SIGINT that can be associated to MTI and IMINT tracks, and on MTI track starts/ends that can be associated to IMINT hits.

- **Key themes / technologies**

  ATIF is based on multiple hypothesis tracking (MHT) technology. The MHT approach uses statistical models of target state dynamics across move-stop-move cycles and uncertainties in sensor kinematic and attribute information. The practical application of MHT technology relies on optimization-based hypothesis management methods to maintain and score multiple hypotheses, while scaling to realistic problem sizes. ATIF currently runs in greater than 10x real time on scenarios with 600+ targets on a standard PC configuration and operationally realistic sensor sampling rates (e.g., ~10 secs MTI sampling period).

  ATIF has a generic sensor interface that allows it to be straightforwardly upgraded to accept tracks from multiple sensors of the same type (e.g., multiple SIGINT correlators), to fuse new attributes (e.g., geometric attributes), and to process data from new sensor types (e.g., unattended ground sensors).

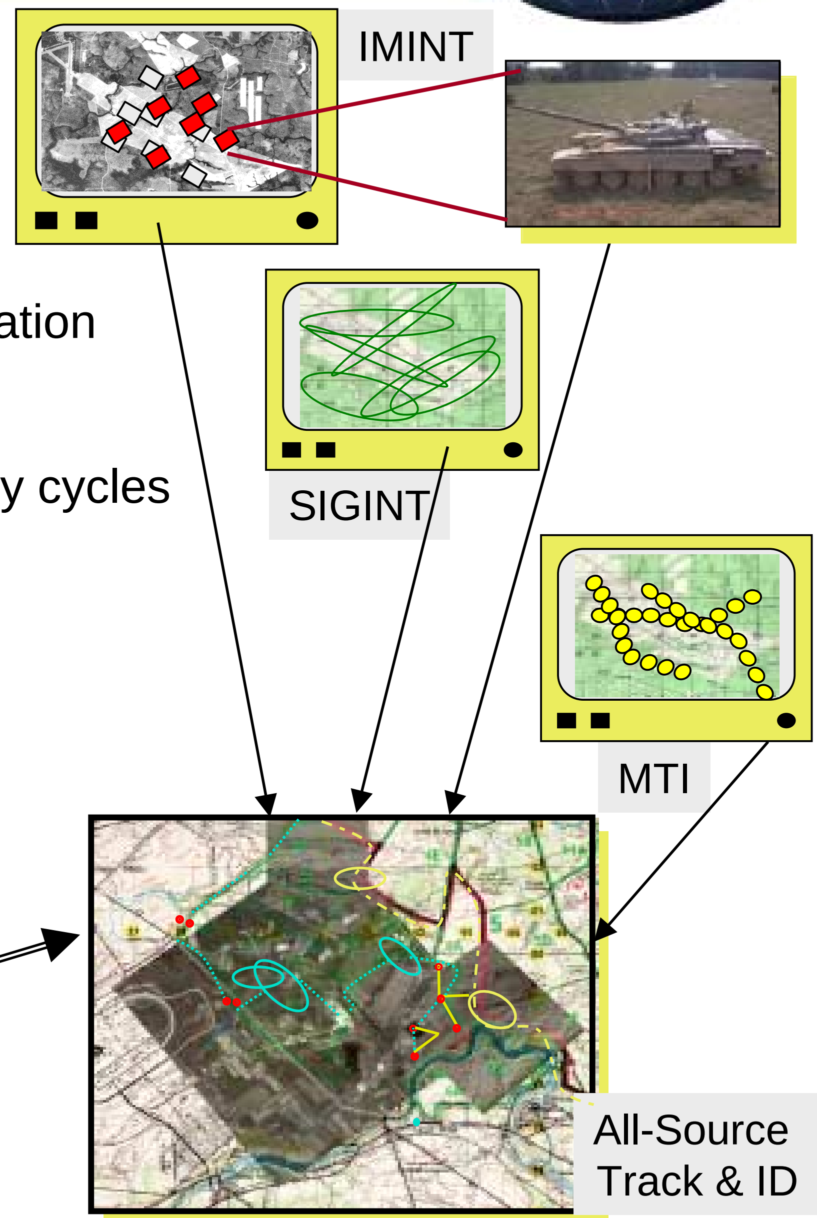
- **Significance:**

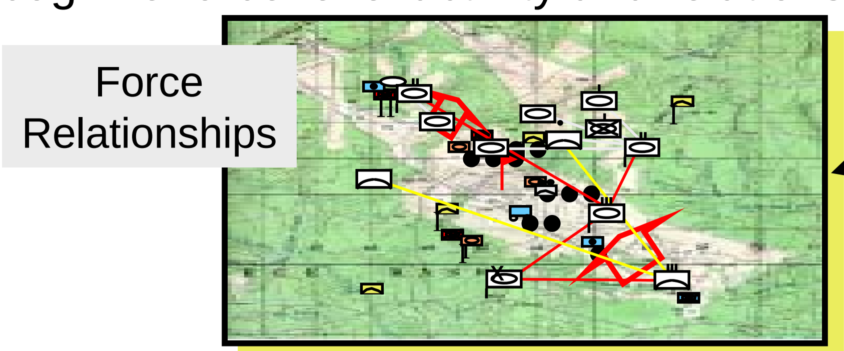
  ATIF technology will enable much more effective exploitation of multi-INT sensor data for situational awareness and target planning

  The capability to maintain track through move-stop-move cycles will ease burden on analysts and operators via extension of track continuity.

All-Source Track & ID Fusion Approach

- **Fuses Change Detector outputs**
  - Detections, Tracks, Identifications, Features
  - MHT (Multiple Hypothesis Tracker)
  - Support sensor tasking
- **Target Identification**
  - Fuse and Maintain SIGINT/ IMINT Identity Information
  - Model Based Classifier
    - EO and SAR classification of vehicles
  - SIGINT ID features link with moving and stationary cycles
- **Target Track Continuity through move-stop-move cycles**
  - Fuse GMTI and SIGINT when moving
  - Fuse IMINT and SIGINT when stopped
  - Increase Track Length Relative to MTI Alone
  - Recognize force level activity and relationships





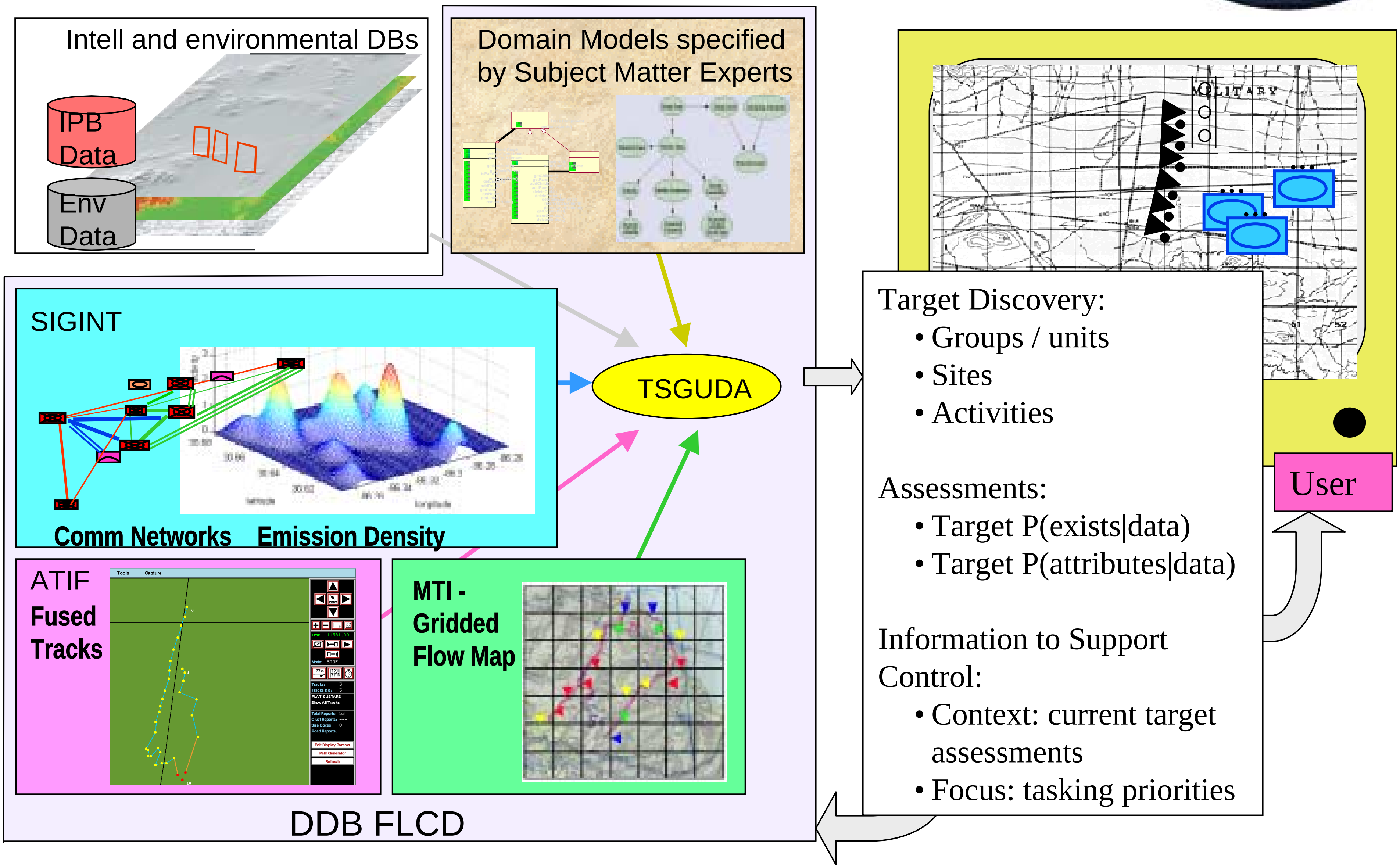
Force Level Change Detection (FLCD)

- **FLCD Goals:**
  The goal of this experimental thread is to establish a foundation for automated reasoning about force level groups and activities as supported by evidence from multiple platform, multi-INT fused products in the dynamically updated data base.

  The approach introduces new technologies focused on bridging the gap between bottom up evidence based deterministic fusion and top down probabilistic reasoning. Tactical bottom up fusion is typically used to support IPB, I&W, and ATR. It answers the question, “What does the evidence mean?”. Top down reasoning is used tactically to make decisions about taking action over expected threat and targeting opportunities. It typically asks the question, “Does the evidence support my belief about what is happening?”

  Objectives that support these goals include:
  - Designing an application framework and engine to identify sites, groups, units and determine their associated activities
  - Track state changes of these force level activities across space and time
  - Characterize and assess the confidence level of reported conclusions
- **Key themes / technologies:**
  The key hypothesis is that automated force level reasoning is feasible and can yield meaningful force level change detection. The DDB component developed to test this hypothesis is called TSGUDA (Tactical Site, Group, and Unit, Detection and Assessment). TSGUDA technology combines other DDB fused products and coarse data, including ATIF tracks SIGINT emission densities, and MTI flow densities with weather, terrain and feature data, and current situation information using:
  - Bayes-net and frame system knowledge representation
  - Model Fragments specified by domain subject matter experts
  - On the fly hypothesis generation with multiple hypothesis management and control algorithms
  - The fidelity of force level hypotheses are measured by situation metrics that include P(D) and P(FA) for groups
- **Significance**:
  Successful detection and tracking of site/unit/group activities (i.e. at acceptable confidence levels) will :
  - Establish the foundation for providing interactive user control over the fusion process
  - Provide context required to make COA decisions over tactical targeting activities
  - Provide the basis for prioritizing sensor tasking and collection requests

Force Level Change Detection



◆ **TSGUDA : Tactical Site, Group, and Unit, Detection and Assessment** ◆

DDB Algorithm Relationship

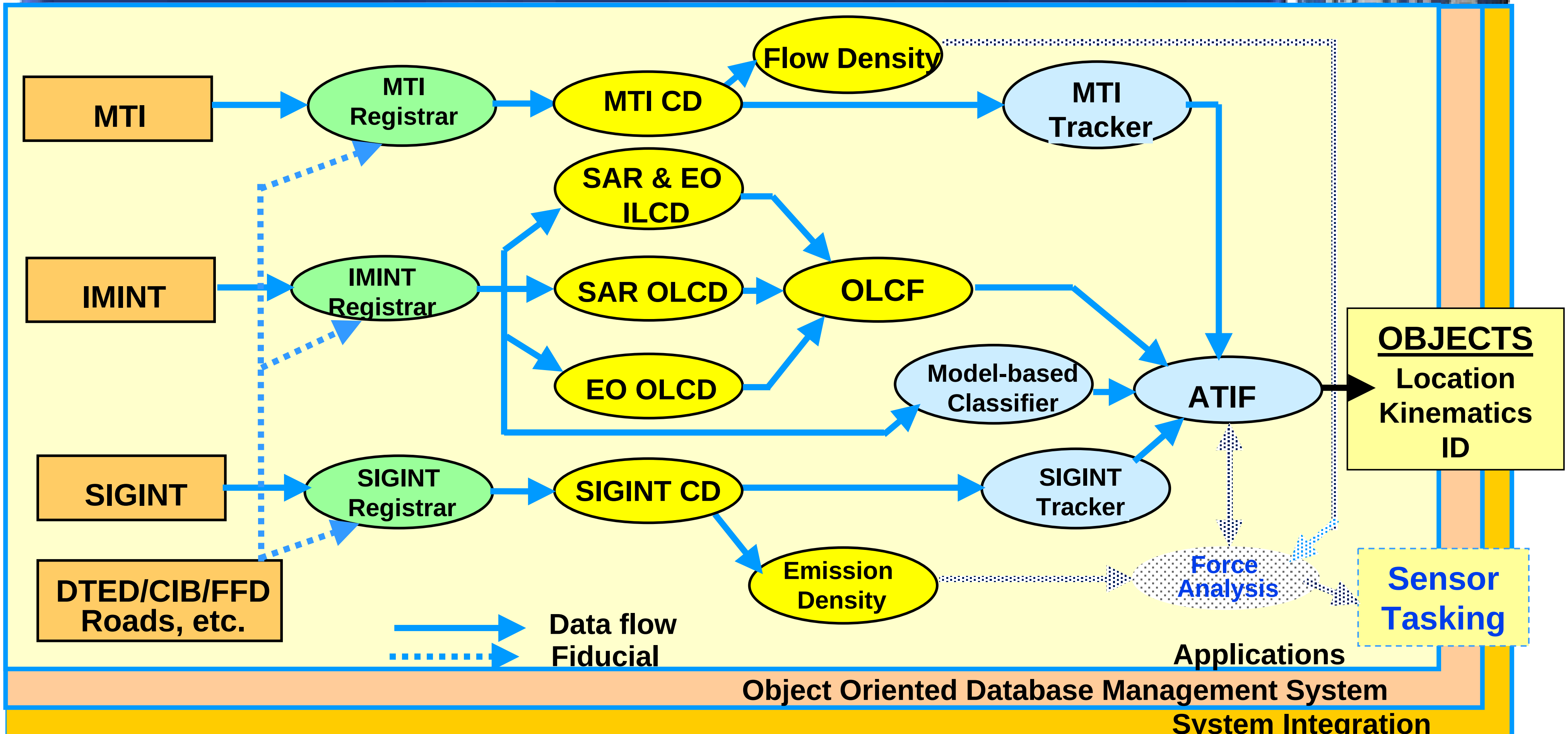
The DDB Algorithm Relationship chart depicts notional data flow through the algorithms and is not intended as a "wiring diagram". The algorithms interface with sensor data and derived products which reside in an object oriented database. An ongoing system integration and system modeling effort identifies integration issues and bounds fused system performance expectations.

MTI, IMINT and SIGINT data are co-registered to terrain information (DTED, CIB, FFD). Invariant features are used as match points, for example, a stationary rotator that emits can be detected by MTI as it sweeps, "seen" by IMINT and "heard" by SIGINT. High resolution IMINT is used to refine terrain information for the next registration cycle.

Co-registered multi-sensor data is used to rapidly create Normalcy Models. Change Detectors use the normalcy models as the reference to process subsequent ingested data. Image Level and Object Level Change Detectors (ILCD & OLCD) process IMINT data. The Object Level Change Fusion (OLCF) process fuses the ILCD and OLCD outputs which de-correlates false alarms and increases probability of detection. OLCF and the MTI and SIGINT change detectors provide track data to the All-source Track and ID Fusion (ATIF). OLCF cues the Model Based Classifier (MBC). The MTI and SIGINT change detectors also provide flow density and emissions density, respectively, to the Force Level Change Detector (FLCD).

ATIF, including the FLCD function, fuses all the processed data into an integrated track file that, for the first time ever, tracks ground objects through their "move-stop-move" cycles and identifies the objects. ATIF maintains multiple hypotheses regarding association of data to objects and tracks, and uses succeeding data to resolve ambiguities and improve track estimation quality. FLCD uses the output of the ATIF process combined with flow and emissions density to identify activity related to sites, groups and units.

DDB Algorithm Relationship



- **Registration:**
  - Shared multi-spectral fiducial
  - Salient feature matching
  - Iterative refinement

- **Change Detection:**
  - Adaptive background modeling (normalcy)
  - Spatial and temporal pattern analysis
  - Tripwires

- **All-Source Track & ID:**
  - Correlates detection features from sensors
  - Accumulate over time
  - Maintain through move/stop/move cycles

I LCD: Image Level Change Detection ◆ OLCD: Object Level Change Detection ◆ OLCF: Object Level Change Fusion ◆ ATIF: All-Source Track & ID Fusion